§9. Compact Reactor Design of Modular Heliotron Reactor (MHR)

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MHR, which has the modular coils sectored by toroidal field period (toroidal pitch number, m), has a well-defined and efficient closed helical divertor configuration compatible with modularity [1]. For the modular system it is difficult to increase the magnetic field because of its complicated structure in the coil system. However, MHR has the property that, as the coil gap, Δ_{gap}, between the modular coils increases, the plasma aspect ratio decreases. It is an approach for the compact system to increase the coil gap. We have carried out the physics optimization of MHR based on MHD equilibrium and stability, neoclassical transport and particle confinement[2].

Figure 1 shows coil gap dependence of confinement fraction, effective helical ripple and plasma aspect ratio for MHR system with the optimal coil modulation. The confinement fraction and effective helical ripple amplitude are estimated by minimum-B contour and neoclassical ripple transport model. As coil gap increases, neoclassical transport increases and confinement fraction decreases. By optimizing the magnetic surface shape and magnetic axis position, so that magnetic surface is vertically elongated and magnetic axis shifts torus-inward, confinement properties of MHR are improved. According to transport analysis, effective helical ripple should be less than 5%. It is future subject that the neoclassical ripple transport is reduced further.

Figure 2 shows the dependence of the construction cost and field strength, major radius of MHR on plasma aspect ratio. Open and close symbols correspond to compact design (δL>0.4m) and standard design (δL>1.0m), respectively. Here, δL denotes the coil to plasma clearance, which is the key issue of the design of the compact reactor. We adopt compact design to MHR. We show the typical design candidate with 10 modular coil system in Table I. Here we select the R=10m, $\langle a_p \rangle$=1.7m, B_0=6.1T, magnetic axis torus inward shift and vertical elongated plasma shape and Δ_{gap}=8° (1.4m). It should be noted that MHR coil size is 1.0x1.0m^2 applying a coil current density 30A/mm^2. It has the plasma aspect ratio 6, effective helical ripple 8.7% at $r/\langle a_p \rangle$=2/3 and $\langle\beta\rangle$ limit 4.2% and the construction cost is 21 yen/kW.

We can proposal further compact MHR design by reducing m number of the coil system. In Fig.1, the plasma aspect ratio for MHR with 8 modular coils, m=8, is also shown with closed triangles. It is noted that in the case of Δ_{gap}=8°, MHR with m=8 has the plasma aspect ratio 4.5. Based on database for MHR with A_p=5,7,10, we can estimated some reactor design parameter for MHR with m=8. The roughly estimated design parameters are the following as toroidal field on axis 6.0T, major radius 8.9m and coil to plasma clearance 0.37-2.0m. For a design with m=8 it costs 18 yen/kW. The physical optimization is future subject for m=8 MHR.

[1] K.Yamazaki et al. Proc.16th IAEA Fusion Energy Conf., Motreal, IAEA-CN/G1-5.
[2] A.Sagara et al. Proc.17th IAEA Fusion Energy Conf., Yokohama, IAEA-CN-69/FTP/03(R).

Parameters	LHD	MHR
major radius : R (m)	3.9	10
av. plasma radius : <ap> (m)	< 0.65	1.7
fusion power : Pf (GW)	-	2.7
external heating power : Pex (MW)	< 20	50
neutron wall loading (MWm-2)	1.5	3
toroidal field on axis : B0 (T)	4	6.1
average beta : < β > (%)	5	4.20
enhancement factor of tLHD	-	2
plasma density(e20m-3): ne(0)	1	3.8
plasma temperature : T(0) (keV)	> 10	15.6
number of pole :l	2	2
toroidal pitch number : m	10	10
pitch parameter : γ	1.25	1.25
coil modulation : α	0.1	-0.3
coil gap : Dgap (deg.)	-	8
av. helical coil radius : <ac> (m)	0.975	2.5
coil to plasma clearance : δL (m)	0.16	0.4~1.3
coil current(MA/coil) : IH	7.8	30

Table I MHR parameters table

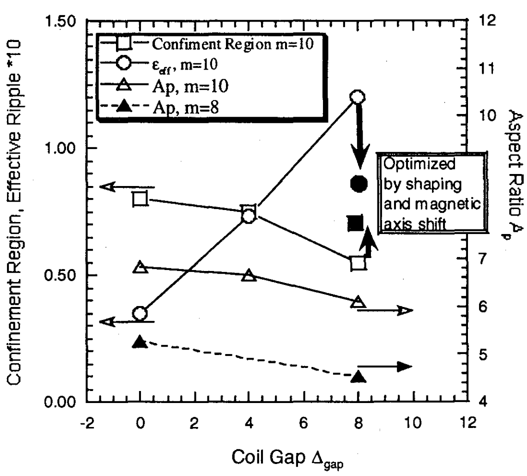

Fig.1 Coil gap dependence of confinement parameters and plasma aspect ratio.

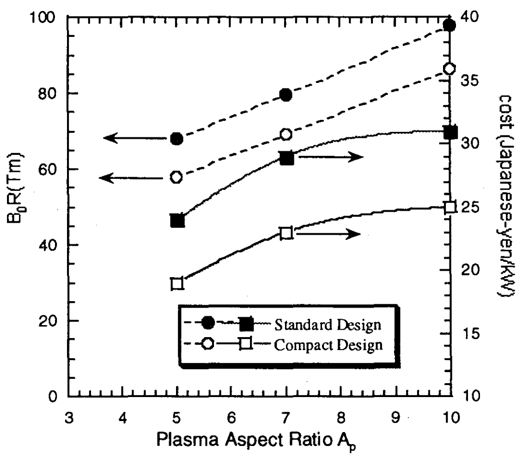

Fig.2 Plasma aspect ratio dependence of major radius, field strength and construction cost.